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ROENTGEN STEREOPHOTOGRAMMETRIC ANALYSIS OF GROWTH PATTERN AFTER
SUPINATION-ADDUCTION ANKLE INJURIES IN CHILDREN

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ABSTRACT

In a prospective study of supination-adduction ankle fractures in children the posttraumatic growth pattern was registered with a roentgen stereophotogrammetric technique allowing exact determination of the growth rate within three months after fracture. It was possible to predict future growth pattern within six months.

The supination-adduction injuries (10 cases) were separated into two stages according to Gerner-Smidt. One Stage I injury (physeal separation through the distal fibula) showed a growth stimulation. Nine Stage II injuries (including a fracture through the medial malleolus) showed four types of growth pattern besides symmetrical growth.

The Salter-Harris classification alone showed no obvious correlation to the posttraumatic growth pattern, whereas factors such as age at injury, stage of injury, displacement, and treatment in combination with the Salter-Harris classification contribute to a better prediction of risk of deformity. It was found that displaced Stage II injuries in the younger child had the highest risk of developing a clinically significant varus deformity.

Early determination of the posttraumatic growth pattern is of crucial importance in SA injuries with a high risk of growth deformities. Operative treatment in order to restore normal growth can be performed before a severe deformity has developed.

INTRODUCTION

Supination-adduction trauma to the ankle in children is the most common cause of a fracture through the growth plate of the distal fibula. When this injury has occurred further bending of the ankle will cause a fracture of the medial malleolus by pressure from the talus.

Anatomically the fibular fracture through the growth plate is of Salter-Harris Type I; more seldom of Type II or III. The medial malleolar fracture is usually of Type III; more seldom of Type IV or zigzag pattern. This injury can result in varus deformity, as known for more than a century (8,9,34,36).

The mechanism of developing growth disturbance after physeal fractures was discussed by Vogt (49); factors such as trauma to the growth cartilage, insufficient blood supply, and extensive callus formation were considered aetiological factors. Later factors such as crushing of the growth plate (1,2,31,37,40), disturbed vascularization (21,24,48), extent of displacement (25,30), adequacy of reduction (33,37,45), type of reduction (6,37), type of osteosynthesis (11,38,43), secondary infection (5,6,37), and time of immobilization (6,16,20) have been associated to the risk of developing a growth disturbance. Also the child's age at the time of injury is of crucial importance for the consequences of a growth disturbance (7,25,37,46).

Previous reports (1,12,19,20,26,31,47) have stressed the high risk of developing a varus deformity and unequal bone length after a supination-adduction injury.

The roentgen stereophotogrammetric method (3,10,25,35,39,41,42) has proved valuable in the determination of the early posttraumatic growth pattern. Information about the growth can be obtained within three months after fracture (25). This study evaluated with a roentgen stereophotogrammetric method the posttraumatic growth pattern after supination-adduction (SA) type of injury.

The results were compared with the Salter-Harris classification and with other factors such as skeletal maturity, type of trauma (stage),

displacement, and treatment in order to improve the possibilities to predict the prognosis of these injuries.

MATERIAL AND METHOD

Ten cases (five boys aged 10-15 years, and five girls aged 6-13 years) had injuries classified as due to supination-adduction. The ankle fractures were classified traumatologically according to Gerner-Smidt (18) and anatomically to Salter and Harris (40).

The Stage I injury (one case) is a physeal separation through the distal fibular growth plate (S-H Type I, II, or III). The second stage (nine cases) includes an oblique or vertical fracture of the medial malleolus (S-H Type III or IV). Sometimes the fracture runs in a zig-zag pattern (Z).

The roentgen stereophotogrammetric method

Spherical tantalum balls 0.5 mm diameter are inserted at operation or percutaneously in local anaesthesia after fracture healing (3,25).

Three to five balls are inserted at each side of the growth plate in the distal tibia on the injured side, whereas one ball is inserted on each side of the growth plate in the distal fibula on both sides, as well as in distal tibia on the intact side.

The patients are followed with roentgen stereophotogrammetry. The first examination takes place one to three weeks after implantation of markers. The next examination is performed one month later. Examinations are then performed at intervals of three to six months during the first year and then at intervals of six to twelve months if further follow-up is indicated.

At the roentgen stereophotogrammetric examination, the ankle is placed in a Plexiglas calibration cage with metal markers. Bi-planar technique is employed. The two roentgen tubes expose the films simultaneously. The body is shielded with a lead apron. The radiation dose for one roent-

gen stereophotogrammetric examination was evaluated and found rather constantly to be about 0.7 mGy for each roentgen stereophotogrammetric examination. The radiation dose for a conventional X-ray examination of the ankle was found to vary between 1.3 mGy to 10 mGy depending on the technique.

The films are evaluated in a precision instrument for aerial photogrammetry: Wild Autograph A8. The co-ordinates for the centre of the bone markers are recorded and related to the laboratory co-ordinate system defined by the calibration cage.

Growth analysis

The distances between the bone markers at each roentgen examination are calculated, and the change in distances between the bone markers in the epiphysis and the metaphysis between two examinations are taken as the longitudinal growth. Method error or growth evaluation (longitudinal growth) is about 30 to 50 μm . This corresponds to about 1 μm for daily growth registered at monthly intervals.

Kinema analysis

In a separate computer program (KINEMA) for rigid body kinematics, the metaphyseal and epiphyseal markers are modelled as rigid bodies, and movements are calculated of the whole epiphysis in relation to the metaphysis. The error of Kinema calculation is about 50 μm and $0.1\text{--}0.2^\circ$ (standard deviation) between examinations for translations and rotations, respectively.

On the injured side where three to five tantalum balls were inserted on each side of the growth plate, the longitudinal growth was calculated as the translation along the longitudinal axis of the bone according to Kinema analysis (25). Asymmetrical growth was given as rotation of the epiphysis about the three axes and/or growth rates in different regions of the growth plate. The accumulated growth was calculated according to Kinema in distal tibia on the fractured side, whereas in the other three regions (distal fibula fractured side, distal tibia, and fibula intact side) accumulated growth was registered as changes of distances between single pairs of tantalum balls.

RESULTS

The posttraumatic growth pattern was separated into five types: symmetrical growth (➡), initial and temporary growth stimulation (↗), initial and temporary growth retardation (↘), initial and permanent growth retardation (↙), and initial and permanent growth arrest (↓) (25).

Concerning the growth rates of distal tibia and fibula on the intact side, there was a difference between different individuals at the same chronological age depending on different skeletal maturity.

Table I lists the posttraumatic growth pattern, skeletal maturity, type of trauma and stage, fracture type according to Salter-Harris, displacement, and treatment.

Growth patterns

Symmetrical growth during the first period of registration will remain: a small variance can develop (case one; distal tibia, case five; distal tibia, case six; distal fibula, and case seven; distal tibia and fibula).

Growth stimulation registered during the first period can remain for about one year and a half after fracture (distal fibula, case four) or for shorter periods and passes usually into symmetrical growth, but growth stimulation followed by retarded growth does occur.

Growth retardation lasting at most six months after fracture will pass into symmetrical growth (25) or growth stimulation (case six; distal tibia).

Growth retardation lasting more than six months and growth arrest during the first period of registration will remain (case three, case five; distal fibula, cases eight, nine and ten).

Growth within the growth region

Initial and progressive growth retardation in the distal tibia is sometimes associated with an asymmetrical growth within the growth region

Table 1. Clinical summary

Case	Sex	SA stage	Age at injury, years	Skeletal maturity*	S-H Fib	Displacement max., mm Fib	Treatment in addition to plaster	Observation time in months	F i b u l a		I b i a	
									Accumulated growth difference, mm	Accumulated growth difference, mm	Growth pattern	Growth pattern difference, mm
1	M	I	10	11.5	I	- <2	-	3-19	↗	0.2	↗	0.1
2	F	II	6	6.5	"	III <2	<2	2-6	↗	0.6	↗	1.2
3	F	"	6	7	"	Z(IV) "	2-5 closed red. pinning	2-14	↗	-2.5	↗	-2.5 ⁺
4	F	"	8	9	"	III "	<2	2-19	↗	2.1	↗	1.1
5	F	"	9	8	"	Z(IV) "	2-5 open red. 0.2-17, 5 pinning		↗	-2.4	↗	-0.9
6	M	"	11	11.5	"	III "	<2	2.5-25	↗	-0.4	↗	0.8
7	F	"	13	13.5	II	" "	<2	4-9	↗	-0.4	↗	0.3
8	M	"	13	12	"	" "	2-5 open red. pinning	3-29	↗	-5.0	↗	-5.7
9	M	"	14	14	I	" "	<2	3-11	↗	-1.1	↗	-1.1
10	M	"	15	14	"	" >5	>5 open red. screws, pinning	3-17.5	↗	-0.7	↗	-1.3

* according to Greulich-Pyle (22)

+ asymmetrical growth within the growth region

Table 2. The Salter-Harris classification compared with the post-traumatic growth pattern of individual injuries.

Salter-Harris		G r o w t h p a t t e r n				
		→	↗	↘	↖	↓
Fibula	I	1	3		2	2
	II	1				1
		2	3		2	3
Tibia	intact	1				
	III	1	2	1		3
	Z (IV)	1			1	
		3	2	1	1	3

(case three). Also growth stimulation and temporary growth retardation may be associated with asymmetrical growth within the growth region.

Comparison with the Salter-Harris classification

The Salter-Harris classification alone showed no obvious correlation with the posttraumatic growth patterns of individual injuries (Table 2). In the distal fibula, eight Type I injuries showed four types of growth pattern. Two Type II injuries showed growth arrest or symmetrical growth. In the distal tibia, seven Type III injuries showed four types of growth pattern, and two Type IV (Z) injuries showed permanent growth retardation or symmetrical growth.

To illustrate the different posttraumatic growth patterns, some cases are reported in detail.

CASE REPORTS

Case 4. Girl (I.K.) aged eight years fell off a bicycle and suffered a Stage II injury. Salter-Harris Type I through the distal fibula and Type III through the distal tibia. Minimal displacement.

Three periods of registration: 2-3½, 3½-7, and 7-19 months after fracture.

In the distal tibia on the fractured side a growth stimulation was registered during the first two periods (fractured side 24 and 23 $\mu\text{m}/\text{day}$, intact side 16 and 20 $\mu\text{m}/\text{day}$). During the third period the growth rates were almost equal (17 to 18 $\mu\text{m}/\text{day}$)(Fig. 1).

In the distal fibula the growth rate was higher on the fractured side during all periods (fractured side 26, 21, and 17 $\mu\text{m}/\text{day}$, intact side 18, 15, and 12 $\mu\text{m}/\text{day}$)(Fig. 1).

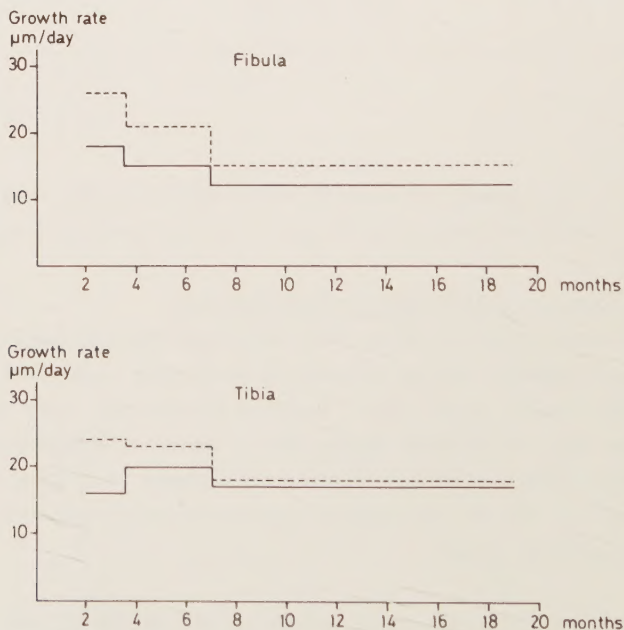


Fig. 1 Case 4.

Growth rate distal fibula (top), distal tibia (bottom). Dashed line - fractured side, full line - intact side.

Case 5. Girl (M.L.) aged eight years jumped from a height and suffered a Stage II injury (Fig. 2 a and b). Salter-Harris Type I injury through the distal fibula and a fracture through the medial malleolus running in a zigzag pattern detaching a small metaphyseal fragment (Z or S-H Type IV). Displacement of about 4 mm. Open reduction and internal fixation with Steinmann pins was performed. Tantalum balls were inserted during the operation. Postoperatively radiographs showed no displacement (Fig. 2 c and d).

Four periods of registration: 10 days - $1\frac{1}{2}$ months, $1\frac{1}{2}$ -4, 4-9, and 9- $17\frac{1}{2}$ months after fracture.

During the first period including the time of fracture healing there was an instability between the fracture fragments. The posttraumatic growth pattern was determined from the second period of registration.

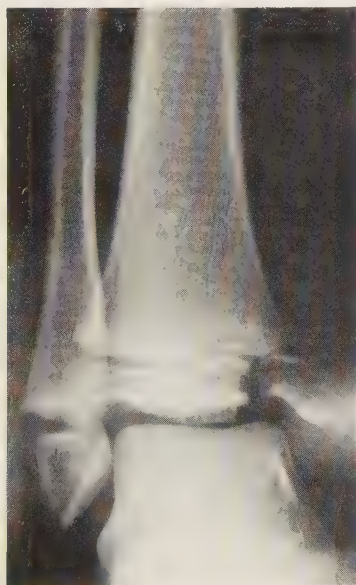


Fig. 2 Case 5.

a - AP.

b - Lateral.



Fig. 2 c



Fig. 2 d

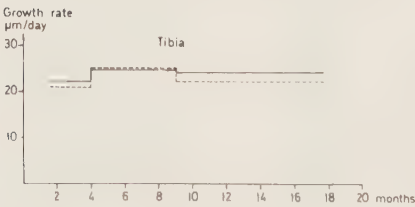
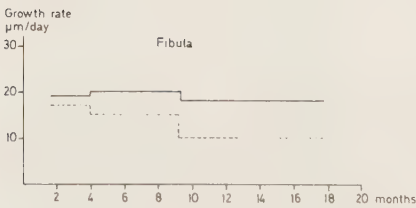


Fig. 2

c - Five weeks after fracture. AP.
d - Five weeks after fracture. Lateral.

e - Growth rate distal fibula (top), distal tibia (bottom). First period of re-
gistration excluded due to instability of bone markers.
Dashed line - fractured side, full line - intact side.

fig. 2 e

In the distal tibia on the fractured side the growth rate was 13 um/day during the first period of registration (10 um/day medially, 14 um/day laterally). On the intact side the growth rate was 18 um/day during the same period. During the next three periods the growth rates were rather equal (Fig. 2 e).

In the distal fibula the growth rate was 19 um/day during the first period on the fractured side, 15 um/day on the intact side. During the next three periods the growth rate was somewhat higher on the intact side (intact side 19, 20, and 18 um/day, fractured side 17, 15, and 10 um/day)(Fig. 2 e).

Case 3. (A.P.) aged six years fell from a swing and suffered an ankle fracture: widening of the distal fibular physis laterally and displacement of the tip of the distal fibular epiphysis medially compared to the opposite side (S-H Type I). In addition there was a minimal fragment at the tip of the distal fibular epiphysis. Fracture through the medial malleolus running in a zigzag pattern detaching also a minimal metaphyseal fragment (Z or S-H Type IV). Proximal and medial displacement of about 2-3 mm, and a considerable rotation of the medial malleolus (Fig. 3 a and b). Because of blistering of the skin closed reduction and percutaneous pinning was performed. Radiographically almost no remaining displacement after reduction and pinning (Fig. 3 c and d).

Five periods of registration: 2-3, 3-6, 6-7½, 7½-11, and 11-14 months after fracture.

Medially in the distal tibia on the fractured side the growth rate was 11 um/day during the first period of registration and decreased down to 1 um/day during the last period. Laterally the growth rate was 26 um/day and decreased to 10 um/day during the last period. On the intact side the growth rate varied between 22 and 28 um/day during the time of observation (Fig. 3 e).

In the distal fibula on the fractured side the growth rate was 19 um/day during the first period and decreased down to 12 um/day during the last. On the intact side the growth rate was 23 um/day during the first period; later it varied between 20 and 24 um/day (Fig. 3 e).

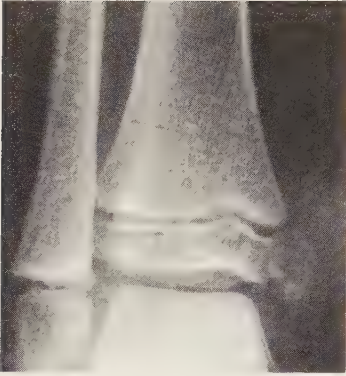


Fig. 3 a



Fig. 3 b

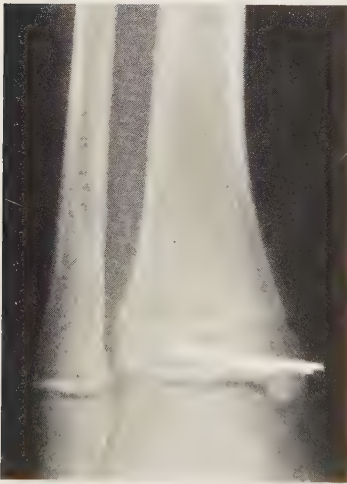


Fig. 3 c



Fig. 3 d

Fig. 3 Case 3.

a - AP.

b - Lateral.

c - Five weeks after fracture. AP.

d - Five weeks after fracture. Lateral.

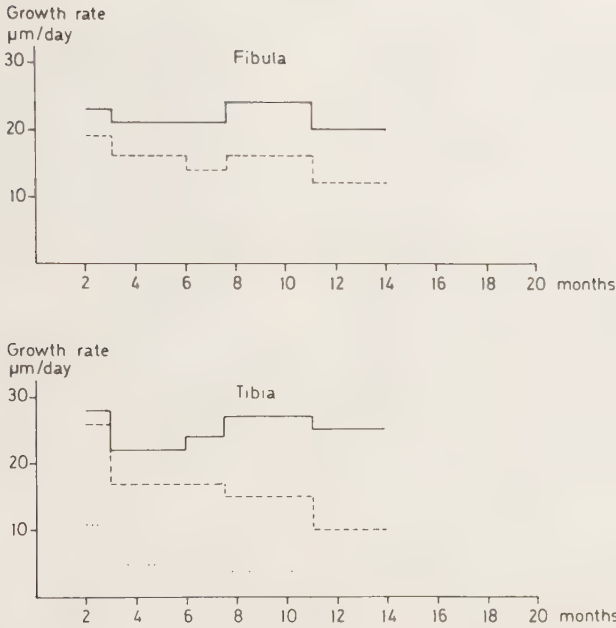


Fig. 3

e - Growth rate distal tibia and fibula. Top: distal fibula. Full line - intact side, dashed line - fractured side. Bottom: distal tibia. Full line - intact side, dashed line - laterally fractured side, dotted line - medially fractured side.

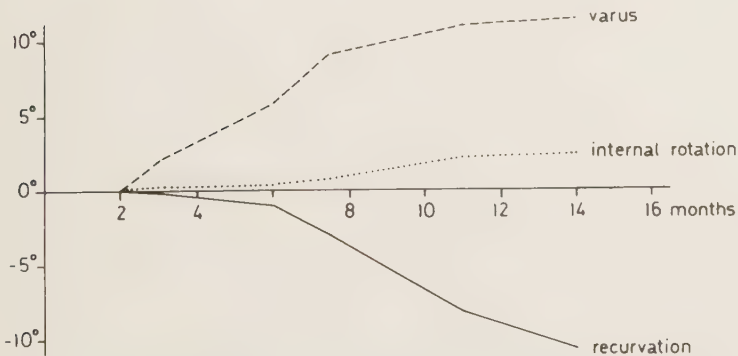


Fig. 3

f - Diagram showing rotation of the distal tibial epiphysis in relation to the metaphysis according to Kinema analysis. Full line - movement about the transverse axis, dotted line - movement about the longitudinal axis, dashed line - movement about the sagittal axis.

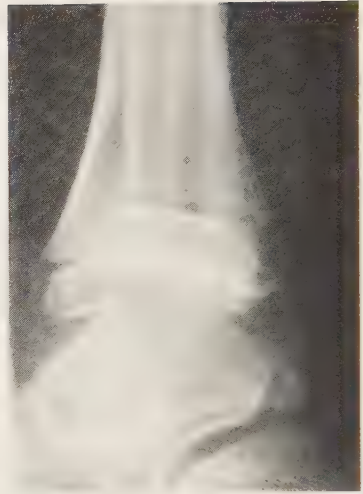
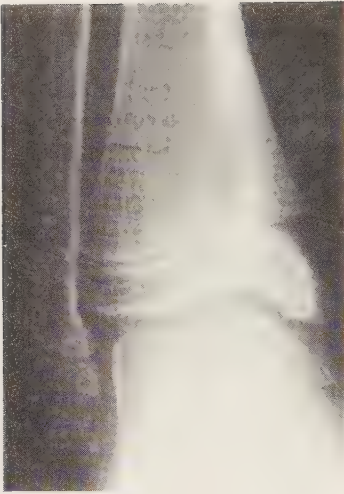


Fig. 3
g - 12 months after fracture. AP.
h - 12 months after fracture. Lateral

Kinema analysis showed a progressive recurvation and a varus deformity of the ankle that 14 months after fracture had reached 11° respectively (Fig. 3 f).

Clinical examination 14 months after fracture showed varus position of the ankle, but normal range of movement of the ankle joint.

Radiographs twelve months after fracture showed an asymmetric condensation line on the AP views. Medially the condensation line was found close to the growth plate; laterally some mm above (Fig. 3 g and h). Fifteen months after fracture the patient was operated successfully according to Langenskiöld (27,28,29).

Case 7. Boy (S-O.N.) aged 13 years suffered an ankle fracture in a motorbike accident. Salter-Harris Type II injury through the distal fibula and a Type III injury through the medial malleolus. Displacement of about 4 mm. Open reduction and pinning was performed. Postoperatively radiographs showed a remaining displacement of the medial malleolus of about 2 mm.

Six periods of registration: 3-5, 5-7, 7-11½, 11½-15, 15-18, and 18-29 months after fracture.

In the distal tibia on the fractured side the growth rate was zero during all periods of registration. On the intact side the growth rate was initially high (22 $\mu\text{m}/\text{day}$), decreased and was zero 1½ years after fracture (Fig. 4).

In the distal fibula on the fractured side the growth rate was zero throughout all periods of registration. On the intact side the growth rate decreased from 16 $\mu\text{m}/\text{day}$ during the first period down to 1-2 $\mu\text{m}/\text{day}$ (Fig. 4).

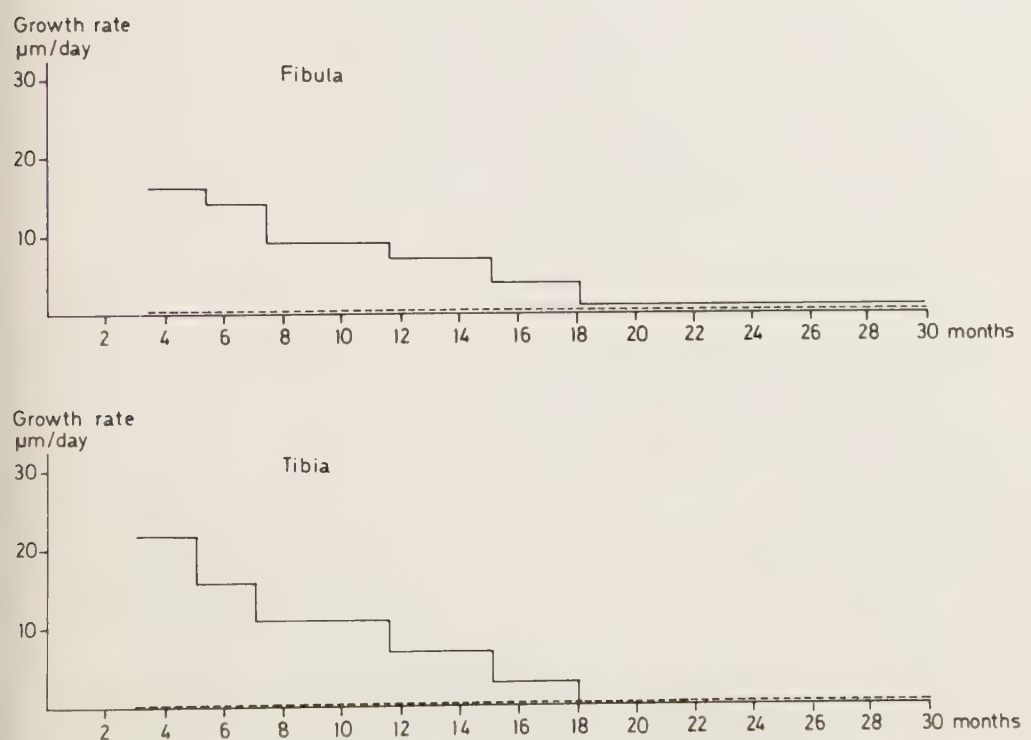


Fig. 4 Case 7.

Growth rate distal fibula (top), distal tibia (bottom). Dashed line - fractured side, full line - intact side.

DISCUSSION

Foucher (17) concluded that, because of different prognoses, it is of importance to separate physeal fractures into intra- and extra-articular. Later Salter and Harris (40) and Rang (37) stressed two important properties of the intraarticular injuries; there is a risk of growth disturbance and of joint incongruity. In some ankle fractures the first aspect is of lesser importance, e.g., in the intraarticular supination-eversion injuries always appearing at high skeletal maturity, whereas supination-adduction injuries can appear when the remaining growth is considerable.

This study showed that the posttraumatic growth pattern after a supination-adduction injury seemed to differ, depending on fracture anatomy, displacement, treatment, and skeletal maturity. In the younger children the fracture through the medial malleolus and the medial part of the growth plate (Stage II) resulted in symmetrical growth, temporary or progressive growth retardation, or a growth stimulation, whereas the older children in general showed a growth arrest. This could be because of a more active growth region in the younger children and a better possibility to regenerate the growth cartilage in the damaged region.

Growth stimulation was found only in patients younger than eleven years, and this growth pattern is regarded as rare after physeal fractures (23, 45) but has earlier been observed where there are injuries due to supination-eversion (25), pronation-eversion (unpublished data), and in two cases with atypical fractures (unpublished data).

The Salter-Harris classification was in this study found to be of minor value in predicting the posttraumatic growth pattern because damage to the entire growth plate (as in the Stage I injury - Salter-Harris Type I-II) or to a localized region of the growth plate (as in the Stage II injury - Salter-Harris Type III-IV) can result in the same growth pattern. However, growth arrest or progressive growth retardation is probably rare in the solitary Stage I injury in the younger child, as no serious problems are reported (18,44). The patient in this study showed a good prognosis consistent with earlier findings. The Stage I injury when

combined with a fracture of the medial malleolus showed a high frequency of growth arrest in the elderly child. This could partly be due to a larger displacement than in the solitary Stage I injury permitting a more extensive damage to the growth plate, as earlier suggested by Lombardo and Harvey (30) in injuries about the knee, and also found among injuries due to supination-eversion (25). In the elderly child the growth plate is more vulnerable to trauma than in the younger child due to different anatomical configuration (25).

The Stage I injury is usually non-displaced or only slightly displaced. According to the literature (18,44) and to this study follow-up because of a possible growth disturbance is not usually indicated.

Undisplaced or slightly displaced (< 2 mm) fractures of Stage II showed a good prognosis in the younger child, whereas one boy aged 14 years with an undisplaced Stage II injury showed a growth arrest in both distal tibia and fibula. The remaining growth in these ages is low and the leg length discrepancy will be minimal. Earlier, Spiegel et al. (44) found that undisplaced Salter-Harris Type III and IV injuries showed a better prognosis than the Type II injuries.

In displaced Stage II injuries the fracture gap will be filled with more extensive callus (14,45), and the growth plate will not heal with cartilage but with fibrous tissue (32). These factors predispose to growth disturbance. In case three, crushing of the growth plate in and around the fracture can probably explain the progressive deformity, but a small remaining displacement not visible on conventional radiographs can also be an important factor.

Besides asymmetrical growth and progressive varus position of the ankle, another type of deformity was reported by van Assen (4) and Compere (13); the medial malleolus healed to the medial metaphysis, resulting in symmetrical growth but lacking medial support due to progressive upward sliding of the attached malleolus during subsequent growth. Gill and Abbott (19) believed that progressive varus deformity was due to a Salter-Harris Type IV injury, progressive upward sliding of the medial malleolus due to a Type III.

This study showed that displaced Stage II injuries in the younger child have the highest risk for developing a growth disturbance yielding clinical problems. McFarland (31) believed that deformity after SA injury was very common, and Aitken (1) believed that about 40% of all injuries developed a deformity. Carothers and Crenshaw (12) reported deformity in three of six cases, but one of these had a partly supramalleolar third degree injury (adduction-compression Stage II according to Gerner-Smidt) (18). Giuliani (20) believed that all supination-adduction injuries sustained at lower ages developed a deformity. Larger studies report a lower frequency; Gerner-Smidt (18) found only one case of 40 re-examined with a varus deformity, Spiegel et al. (44) reported two patients with complications out of 33 re-examined with a tibia Salter-Harris Type III fracture of the medial corner and one with complications out of three tibia Salter-Harris Type IV fractures. However, Spiegel et al. (44) did not consider the type of trauma in their study. The different results reported from various authors could depend on a difference in selection of patients, average age at injury, treatment, and type of classification.

Aitken (2) believed that exact reduction would not improve the prognosis of the SA Stage II injuries, as the growth plate had already been damaged. Contrary to this most authors stress the importance of exact reduction for normal growth (33,40,45), and adequate reduction of injuries displaced more than 2 mm is a prerequisite to minimize the frequency of secondary deformities. Open reduction when necessary should be performed without damaging the growth plate (37). Osteosynthesis should preferably be placed transversely through the epiphysis or through the metaphysis without penetrating the growth plate. Screw fixation through the growth plate can cause growth arrest (45) and should be avoided.

Fixation of the foot in a valgus position (16), or immobilization in Thomas'splint for three to six months (20) have been suggested to avoid a growth disturbance, whereas Dotter and McHolick (15) believed that the duration of non weightbearing played no part for the prognosis. The patients in this study with a Stage II injury were immobilized in a plaster for five to six weeks, as recommended by Rang (38).

Growth retardation lasting more than six months seldom normalizes (25). With this type of growth disturbance and large remaining growth after a SA Stage II injury, operative treatment to restore normal growth should be considered; there is no reason to wait longer, as the deformity will progress and the possibilities for a successful operation will diminish in time.

The roentgen stereophotogrammetric method is valuable for follow-up after physeal injuries in children. The growth rate can be determined within three months after fracture. The type of growth retardation can be determined about six months after fracture. When this technique is not available, repeated radiographical examinations during the first year after fracture is recommended, as signs of a growth disturbance can sometimes be found as early as six to eight months after fracture. However, from radiographs definite judgement between a normal growth or a growth disturbance cannot be made before one year after fracture.

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